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FIELD TESTS USING DEAD RECKONING AND MONOPTIC VIDEO FOR REMOTE LUNAR SURFACE NAVIGATION

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16 ABSTRACT

Field tests of simulated remote lunar navigation are described The navigation system consisted of a dead reckoning unit and a monoptic television unit The traverses simulated lunar sorties partly in terrain but principally in that the navigators had no more advantages than would be had in an actual sortie The tests demonstrated not only the feasibility of such a system for long-range lunar navigation but also the ease of implementation and use

The tests were performed at the United States Geological Survey (USGS), Flagstaff, Arizona

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EDITOR'S NOTE

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SUMMARY

Field tests of simulated remote lunar navigation are described The navigation system consisted of a dead reckoning unit and a monoptic television unit The traverses simulated lunar sorties partly in terrain but principally in that the navigators had no more advantages than would be had in an actual sortie The tests demonstrated not only the feasibility of such a system for long-range lunar navigation but also the ease of implementation and use

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INTRODUCTION

Studies of the guidance and control of an unmanned surface vehicle have been performed by numerous persons over the past few years Most of these studies have been devoted to theory and related computer studies Some studies have been field tests such as the Jet Propulsion Laboratory's navigation tests using landmark navigation[1] Other investigators have looked into the problem of remote driving using a TV camera mounted on the test vehicle. To varying degrees, investigators have addressed themselves to specific areas related to the broad problem of remote guidance and control of a planetary surface vehicle

In this investigation, the authors studied the problem of what constitutes an adequate viewing and navigation system suitable for transportation to, and operation on, a planetary surface During the investigation, answers were also obtained regarding remote-viewing driving. No attempt has been made to determine an "optimum" system Rather, the word "adequate" is meant to convey the idea of a state-of-the-art, simple, reliable,

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1. Ritchie Coryell and David Rubin Experiments in Piloting by Landmark on the Moon Document No 760-37, Jet Propulsion Laboratory, Pasadena, California, April 1, 1969

lightweight system, i e , a system that could be fabricated and used in the near future with a great deal of confidence The authors believe that the system described in this report meets these requirements

The tests were held in the Flagstaff area during July and August 1970 Although it was realized that rain and cloudiness would be higher than average during this time of the year, the decision to test was based on the required timeliness of the results, as well as the necessity to test the view with the sun near its zenith Thus, testing under the full range of sun angle was achieved

TEST OBJECTIVES AND GROUND RULES

The purpose of the tests was to simulate as closely as possible in essential respects the navigation situation that would be encountered in the remote guidance and control from earth of a planetary surface vehicle The mission of such a vehicle would be to execute sorties to predetermined locations of scientific interest. To accomplish this, what would constitute an adequate navigation system? Television will certainly accompany the planetary surface vehicle, so the TV camera could be used for certain navigational tasks. The use of only a TV camera in landmark navigation has already been investigated in some depth Based on this information, as well as on other considerations, it was decided to test the effectiveness of the combination of a TV camera and a simple dead reckoning system This dead reckoning system, consisting of a directional gyro, an odometric system, and a processor, has been described in detail elsewhere[2]

To obtain realistic results, an attempt was made to have maps and photographs of the area to be navigated of no better quality than good-grade Orbiter photographs Furthermore, the persons navigating, i.e., watching the TV monitor and utilizing the dead reckoning outputs (Cartesian coordinates and heading), would be as unfamiliar with the test area as possible, within reason Consequently, none of the navigation targets (except, vaguely, the first one or two) were known to the navigation test subjects The sorties were made up by non-navigating personnel (geologists from the USGS) before the tests

In summary, the ground rules were (1) to navigate a sortie consisting of a sequence of identifiable targets, identification being given by Cartesian coordinates determined by map measurements and a verbal description (sometimes in geological terms) and (2) to navigate by means of a dead reckoning system and a monoptic TV camera Tables 1 and 2 show the checkpoint descriptions of traverses 1 and 2, respectively The navigators were

2. Bobby F Walls, William C Mastin, and Peter H. Broussard, Jr Laboratory and Field Tests on a Lunar Surface Navigation System NASA TM X-64551, August 28, 1970

TABLE 1 CHECKPOINT DESCRIPTION OF TRAVERSE 1

Station Number	North (m)	East (m)	Comments
Start	482 790	207 510	South rim of tuff ring
1a	482 280	207 650	Flow front
2a	481 410	208 040	Large block
3a	481 210	207 605	Interior of Spruhl Crater Points of interest are black ash and basalt spatter on walls
4a	482 650	208 970	Contact low flow front goes under steep flow front
5a	481 900	209 105	Base of Merriam cinder cone
6a	482 890	211 595	Contact at edge of Merriam cinder fan
7a	482 040	212 030	Flow front (young Merriam flow) and cinder slope (Merriam fan)
8a	480 795	212 295	Flow front S Merriam young flow
9a	480 890	210 510	Plug in Merriam vent
10a	480 820	211 110	Rim crest – east Merriam cone
11a	480 440	211 790	Gate – east of Merriam
12a	477 660	213 660	S Sheba flow near reservation fence
13a	476 380	213 100	Road and pipeline intersection (pipeline south of S Sheba)
14a	475 300	213 060	Flow front – S. Sheba flow
15a	472 800	213 600	Meander in San Francisco wash, near reservation boundary
16a	472 230	211 050	Old ranch house – San Francisco wash
17a	470 750	210 100	Gate south of old ranch house
18a	469 160	210 750	Hill crest – north side of Merrill Crater

TABLE 2. CHECKPOINT DESCRIPTION OF TRAVERSE 2

Station Number	North (m)	East (m)	Comments
Start	482 790	207 510	South rim of tuff ring
1b	483 485	207 498	Crater 176 flow above north rim of tuff ring
2b	483 880	208 800	Canyon cut through Kellam Ranch flow.
3b	485 850	209 480	Head of canyon between Crater 176 flow and Kellam Ranch flow scarp
4b	488 810	211 200	Patch of black cinders – gully head south of Roden flow Note fence ahead – wire is down over much of the fence line but someone should watch lead vehicle in crossing it
5b	489 800	212 570	Kaibab outcrop at wash intersection, old fence crosses wash here
6b	489 880	213 000	Spur of Roden flow
7b	489 575	213 400	Trm (Moenkopi) red hill
8b	489 890	209 360	Gate through EW fence

allowed to update the gyro (using a sun compass) whenever desired and to update position as often as desired (the latter depending on the navigators' confidence in their estimate of position, i e , pilotage, swinging angles, etc) In general, the navigators used whatever means available during the testing but stayed within the constraints of a dead reckoning system and a TV system

IMPLEMENTATION

The actual remote-viewing navigation situation involves a remote-control vehicle being controlled from a ground station (which will probably possess elaborate equipment) It was felt that the essentials of remote-viewing navigation could be captured with a much

less sophisticated setup. Rather than using a remotely controlled vehicle, which can become complex, we decided to use a commercially available four-wheel drive vehicle (the Jeep shown in Figure 1) and a driver. The driver could then operate the TV camera and navigation system and monitor information such as coordinates and pan and tilt angles. Because the average speed of a lunar sortie would be very low, the vehicle windows were enclosed and the driver was provided with a monitor by which he could drive and observe. In this manner, a slow speed was necessarily maintained and, additionally, a great deal was learned about remote driving, as well as navigation.

Figure 1. Exterior of Jeep.

The driver of the camera vehicle (Jeep) was also a navigator. Initially, it was planned to have the remainder of the navigation team in a van equipped with TV monitors, maps, etc., and to let them collaborate with the camera vehicle. However, maintaining line of sight between the van receiver and Jeep transmitter would entail frequent moving of the van because of the sortie lengths. Thus, another four-wheel drive vehicle (the Travelall shown in Figure 2) was equipped to accommodate two (if necessary, three) persons to navigate with the Jeep driver. For this purpose, a TV picture was transmitted from the Jeep to the Travelall. This gives the broad picture of the navigation vehicles. How each was equipped is described in detail.

The Jeep was a hardtop version, air conditioned and equipped with over-sized tires for additional ground clearance. The interior of the Jeep is shown in Figure 3.

Figure 2. Exterior of Travelall.

Bracketry was installed on the front of vehicle to allow a TV camera on a pan-and-tilt unit to be mounted. Bracketry design allowed for vertical and lateral adjustment of the position of the camera. The windshield was removed and covered opaquely except for a recess for the monitor directly in front of the driver. Snap-on canvas covers enclosed the windows. To the driver's right was a short rack with a map table on top, and beneath, within easy reach were the controls for pan, tilt, zoom, focus, and iris and the readouts for northings, eastings, and heading from the dead reckoning system. This dead reckoning system is a Bendix two-gyro system (directional gyro and vertical gyro) mounted in the rear of the Jeep, which provided vehicle azimuth and from which vehicle attitude was obtained. The vehicle azimuth was fed into an Aviation Electric computer, which also received distance information from the Jeep odometer and resolved this distance into northing and easting components. On the outside rear of the Jeep was mounted a 115-V, 60-Hz, 2.5-kW generator. In front of the driver and slightly to the left was an engine tachometer to regulate vehicle speed.

The operation of the navigation system depends upon the accuracy with which the directional gyro maintains a reference direction. Because of wheel imbalances and bearing friction, the gyro will drift and must be updated to a celestial reference. When the sun was visible, a sun compass device was mounted on each vehicle for gyro updating. The relationship between update period and navigational accuracy is given in Appendix A. The results of a test to determine the ability to update the gyro using the TV camera to track Venus are given in Appendix B.

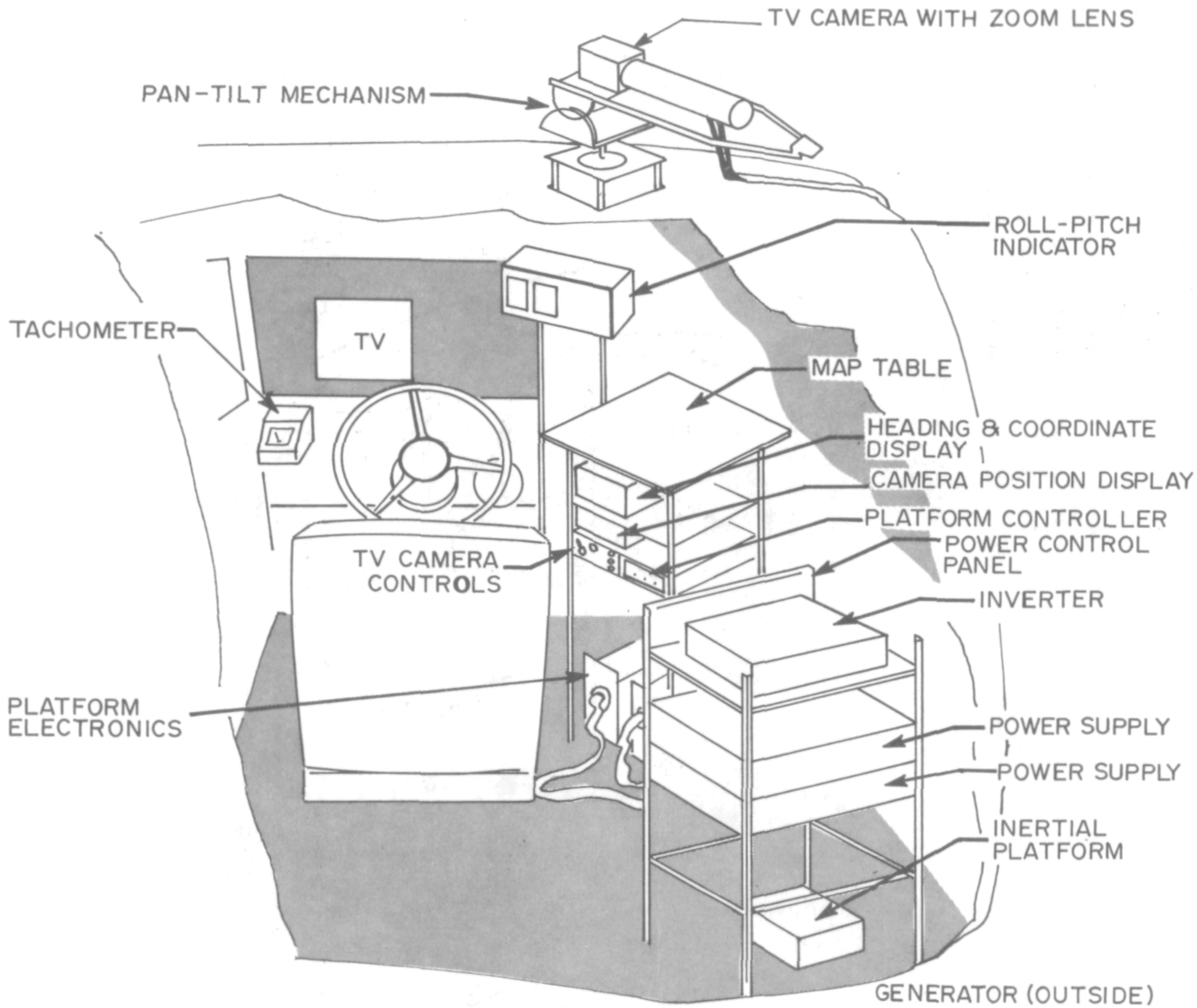

Figure 3. Interior of Jeep.

The Travelall (Fig. 4) was equipped with a vertical panel flush behind the back of the front seat, which ran from the roof to the floor and on which were installed two small fans to draw cool air from the air-conditioned front to the rear. This separator also had dead reckoning readouts (X, Y, and heading) from the dead reckoning system mounted on the Travelall. The second seat was removed and a pair of swivel seats was installed. The dead reckoning system is the prototype of that to be used on the manned lunar rover vehicle. Odometer inputs were pulses generated from wheel-mounted magnets actuating magnetic switches attached to the frame. A table was installed in the Travelall to hold the TV monitor and to provide a place to work. A 1.5-kW, 115-V, 60-Hz generator was mounted on the back of the Travelall. The windows of the rear compartment were covered with aluminum foil. Voice communication between the Jeep and the Travelall was provided by walkie-talkies. In this way, occupants of each vehicle could compare observations and jointly navigate.

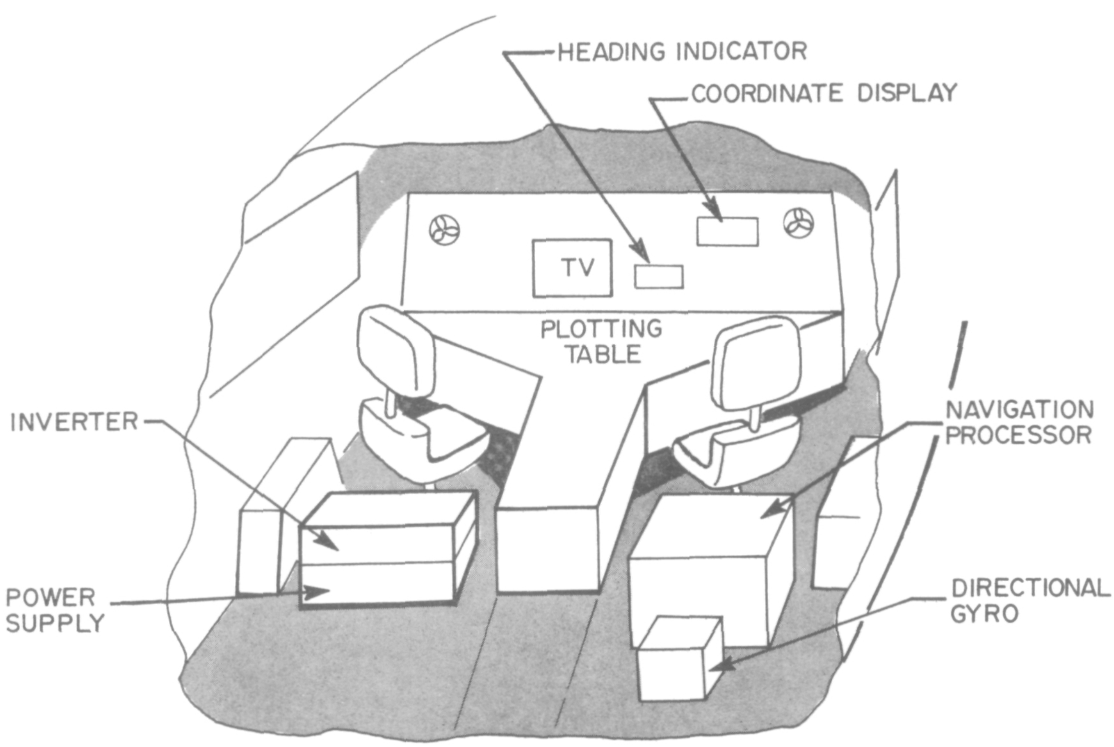

Figure 4. Interior of Travelall.

TEST RESULTS

Usually, no difficulties were encountered in locating the test objectives Figure 5, the map of a sortie, shows the location of the targets (checkpoints) by a cross and the navigators' declared objective by a circle The cross enclosed by a circle indicates that the identified point was the actual target The declaration was based either on target recognition, dead reckoning coordinates, or both (Table 3) In some cases, targeting was exact, e g , ranch house, gate, etc In no case except one, which was later rectified, were the targets missed or misidentified by more than approximately 200 m Some targets, by their very nature, could not be specified uniquely, e g , flow front The navigators, in these instances, used their best judgment in identifying the target

Figure 5 contains the pertinent information concerning target location, vehicle location, navigation system outputs, and, by simple measurement and calculation, vehicle speed The dotted line represents the Jeep location according to the Jeep dead reckoning system Similarly, the solid line represents the Travelall's location according to the Travelall dead reckoning systems Termination of the Jeep and Travelall trajectories and recommencement indicate that the navigation system coordinates were updated This occurs, for example, at targets 12A and 13A, as well as at other points (Targets 9A and 10A were bypassed because of difficult terrain)

From the start of target 7A, the Jeep navigation system suffered from a high gyro drift rate It would be interesting to have the actual vehicle trajectories, but this would have entailed a prohibitive amount of surveying Therefore, actual location is given only in the vicinity of the targets

Finding target 1A was no problem As indicated in the log notes in Appendix A, the navigators struck a line from the peak of the mountain at N478 400 m, E210 900 m through the base of Merriam and found that it passed through the location of target 1A This check was not planned beforehand but presented itself as a logical check at the time Target 2A was visible some distance away and was easily identified It provided a good position update Targets 3A, 4A, and 5A presented no difficulties either, and as can be seen from Figure 5, the misses were small

Considerable difficulties were encountered in going from target 5A to target 6A After becoming stuck and experiencing considerable wheel slippage (which caused the navigators some uneasiness concerning their indicated position), the navigators attempted to follow the contour lines to target 6A However, these worries were largely unfounded error on this target was less than 100 m, and target coordinates and Travelall coordinates agreed within 200 m

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Figure 5. Map of sortie area.

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TABLE 3. POSITION OF STAKE (ACTUAL LOCATION OF VEHICLE)

Station	Trav. A 1:25 000 (m)		Station	Trav. B (m) 1:25 000	Trav. B (m) 1:50 000
1a	X 207 590 Y 482 240	Travelall	1b	X 207 535 Y 483 545	
	X 207 630 Y 481 855	Jeep	2b	X 208 790 Y 483 960	
2a	X 208 065 Y 481 400		3b	X 209 475 Y 485 795	
3a	X 207 470 Y 481 245		4b	X 210 285 Y 488 140	
4a	X 208 955 Y 482 685		4b	X 211 330 Y 489 120	
5a	X 209 040 Y 481 850		5b	X 211 940 Y 489 730	
6a	X 211 660 Y 482 860		6b	X 212 920 Y 489 840	
7a	X 211 965 Y 481 820		7b		X 213 400 Y 489 575
8a	X 212 270 Y 480 740	Travelall	8b	X 209 365 Y 489 825	
	X 212 210 Y 480 680	Jeep			
11a	X 211 815 Y 480 440				
12a	X 213 560 Y 477 530				
13a	X 213 085 Y 476 410				
14a	X 213 060 Y 475 365				
15a	X 213 620 Y 472 820				
16	X 211 065 Y 472 215				
17	X 210 075 Y 470 780				
18	X 210 865 Y 469 250				

At intervals during the sortie, the Jeep driver would record the heading and the camera pan angle when aimed at identifiable prominences. This information was sufficient to calculate one's present position. The navigators were not consistently successful with this method. Reasons for this lack of success are several, not the least of which was the lack of a standard operating procedure. Furthermore, the technique was hampered by inaccurate heading information from the navigation system in several instances and, in at least one case, misreading of the instrument by the operator. However, properly done, the technique is a useful one. An example of this technique is given in Appendix C by the entry at 11.10 a.m., July 24: the "left peak" referred to is N477 300 m, E212 700 m, and the "right peak," N478 400 m, E210 900 m.

A variation of this technique was used when it was noticed that the gyro headings did not agree. (See entry at 2:10 p.m. July 24 in Appendix C.) As explained in Appendix C, the angle between two certain prominences was determined. This angle was used with the recently updated coordinates to determine that this was an appreciable drift problem with the gyro in the Jeep. Based on this graphical technique, both gyros were updated. Note that the Jeep gyro was thereafter updated to agree with the Travelall's (e.g., see entry at 4:24 p.m. July 24 in Appendix C).

Finding target 13A was difficult because the navigators were convinced that they had intersected the pipeline road to the east of the road-pipeline intersection, even though the navigation system coordinates indicated they were west of the target. Thus, a westerly course was pursued until they finally realized that they were too far west. This realization came not from the coordinates but from the Jeep driver who panned and identified a nearby hill. This hill, located at N477 300 m, E212 700 m was found to be almost due north, indicating that the navigators had gone too far west along the pipeline road. With this orientation, the navigators turned around and followed the road east until the road-pipeline intersection was encountered. Another contributing factor in the confusion in locating this relatively simple target was that the Travelall occupants interpreted target 13A (road and pipeline intersection) to mean that the road paralleling the pipeline (which we were on) would cross over the pipeline; hence, a different road crossing at right angles to the one being traversed came as a surprise. Actually, it turned out later that the navigators originally struck the pipeline road only about 100 m west of the target before commencing the fruitless search to the west.

Target 14A presented no difficulties but disclosed a situation that can occur with monoptic viewing, i.e., the merging or blending of close, low-lying ridges with more distant, higher ridges. In this case, the flow front merged with Sheba to give a confusing picture until it was realized what had happened. With reference to the 6:47, July 24 (Appendix A) entry indicating we might be too far south, Figure 5 shows we were about 100 m north of the target. However, navigators were confident enough in their position to update the coordinates to those of target 14A.

Target 15A was located without incident. On this date, we were furnished with 1 25 000 photographs and topological maps, which made navigation more exact, e g , isolated objects such as groups of large rocks could be identified (entry 10 43, July 25), as well as a large tree in the wash (entry 11·17, July 25). By discerning this tree, an accurate location in the wash was obtained. However, the navigation of the preceding days showed that a 1 50 000 scale was adequate for navigation

The "B" sortie on July 29, 1970, strengthened the belief that the system being tested was sufficient for navigation. However, on this sortie, the navigators misidentified one target (4B) by approximately 1 km. This misidentification was the result of a conviction that the traversed terrain had introduced large errors caused by slippage and the perception of an outcropping of lava rocks that was mistaken to be the "patch of black cinders" of target 4B With this error corrected, navigators identified a black outcropping of lava as Kaibob, not knowing that Kaibob was whitish A positive position fix was obtained at target 6B, "spur of Roden flow." On the return the navigators correctly identified targets 5B and 4B. It was shown that if the dead reckoning system output had been followed, the navigators would have come within 200 m of target 4B on the first occasion

GENERAL COMMENTS AND OBSERVATIONS

Tests such as these are necessarily subjective None of the test subjects had previous experience in these types of tests, specifically in the area of navigation and target recognition by remote viewing In spite of this, the subjects encountered no special difficulties in becoming accustomed to the terrain as viewed distortedly through a monoptic, black-and-white TV camera The test subjects did not suffer from any major disorientation Viewing a narrow angular portion of the surrounding territory was not conducive to establishing definite directions (e g , north) in one's mind, as is frequently the case when viewing one's surroundings normally. This probably was a definite advantage, as the navigators could then believe implicitly in the dead reckoning system and certain landmarks without having preconceived notions

The Jeep driver was in a slightly different situation from the subjects in the Travelall in the sense that he could relate camera angle with respect to the Jeep directly, whereas the Travelall occupants had to resort a little more to imagination and maps to obtain proper orientation. However, the Jeep driver navigated less than the Travelall subjects because he was occupied principally with steering the actual vehicle, maintaining the proper heading, detecting and avoiding obstacles, and operating the TV camera Furthermore, he was somewhat limited in space in which to calculate, plot, etc

Generally, the navigators held continuing discussions on probable position, with the Jeep driver relaying his coordinates and heading back to the Travelall occupants who recorded them Although the navigators sometimes disagreed on minor items, navigation was not substantially affected

With respect to whether the TV camera should be gyro-stabilized, the Travelall occupants viewed the monitor under three different dynamical conditions the Jeep moving and Travelall stationary, the Jeep stationary and Travelall moving, and both vehicles moving In none of these cases was there any problem in adjusting one's thinking to the situation Even though rough terrain was traversed, camera motion was never severe enough to substantially affect the viewer's perception (Interestingly enough, two navigators suffered symptoms of vertigo after an all-day session in the Travelall)

Selected portions of the attitudes and attitude rates encountered were recorded A portion of the record of pitch and roll is shown in Figure 6 Rates as high as 20 deg/s were encountered Whereas numerically this does not seem to be very large, it is a jolt to the occupants and equipment in a vehicle

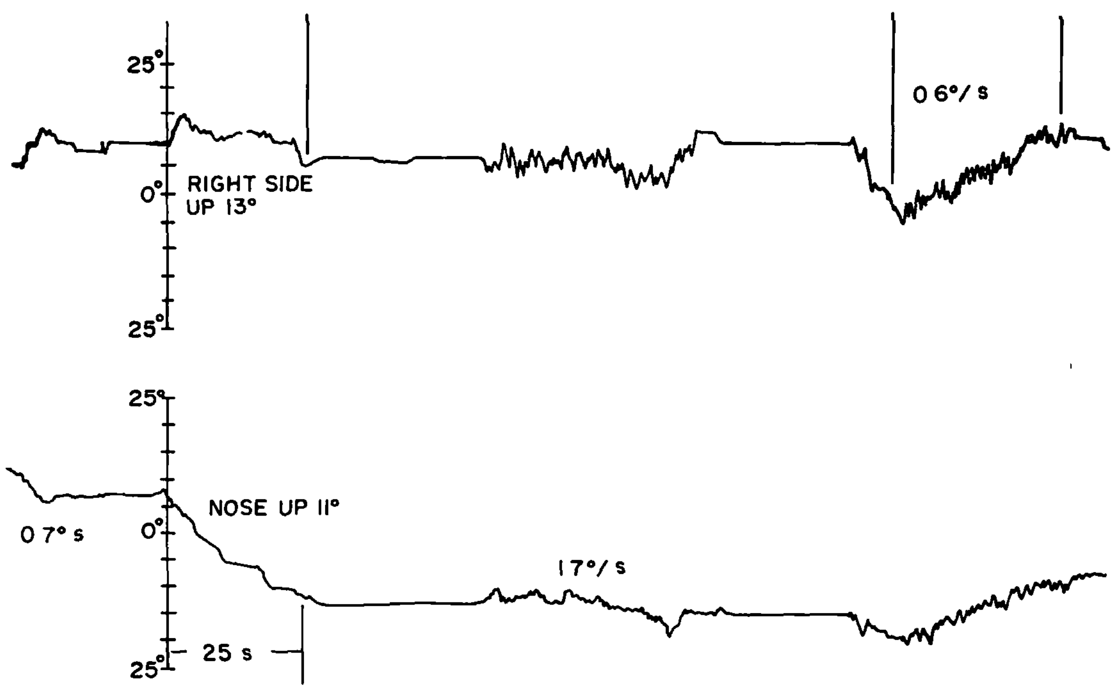

Figure 6 Pitch and roll of Jeep

A COHU model 2305 camera having a 30-deg field of view at near focus and a 7 5-deg field of view under maximum zoom (10 1) was used for driving The zoom proved to be extremely valuable for landmark identification and examination of other objects of identification A 30-deg field of view proved to be entirely adequate for driving

The bracketry of the Jeep was designed to allow for various camera positions Most driving was done with the camera at a position directly above the windshield and centered laterally on the vehicle (See Appendix D for more details on camera positions.) With the camera in this position, drivers found it helpful, when required to make a turn, to train themselves to retain the video picture of the previous few meters on either side of the vehicle This minimized the number of stops and camera pans that had to be made

As stated previously, subjects had no special difficulties in becoming adjusted to viewing the terrain on a TV monitor. As testing proceeded, subjects naturally became more adept at driving, operating the TV controls, and navigation. (Because of gasoline generator noise, as well as noise from other sources, drivers learned to engage the clutch by feel and, if necessary, by tachometer) Some attempts were made in estimating distances simply by looking at the TV picture Success in this was limited but was enhanced if the horizon was in view to give perspective Extremely accurate results were obtained by correlating the camera pitch angle with distance (See Appendix D for calibration.) Having the camera in a depressed position to view the front of the vehicle and the terrain directly in front of the vehicle made driving easier but deprived the driver of aiming points on the horizon (the horizon was not in the field of view), and he had to use the heading indicator to maintain a heading

The TV picture in both vehicles ranged from "extremely good" (particularly in the Jeep) to "somewhat poor" (in the Travelall) The poorer pictures were characterized by light to moderate "snow" on the screen Viewing under these conditions was more difficult but still adequate. Landmarks silhouetted against the horizon were the least degraded by snow, and nearby rocks and bushes became less distinguishable under these conditions

In tests at both the Marshall Space Flight Center and Flagstaff, slopes, mounds, and ditches were difficult or impossible to detect if curvatures were small. In fact, nonflatness was detectable more by changes in lighting of the object than by depth perception Of course, these remarks apply to gentle swells, etc On the other hand, obstacles that presented a hazard could generally be detected, for example, large (20- to 40-cm) rocks presented little hindrance to driving Estimating the size of rocks was more difficult when they appeared in large groups

Lighting conditions proved to have an important influence on driving and hazard detection Up-sun viewing presented few problems, the principal one being glint when the camera was pointed too near the sun Cross-sun viewing seemed to be the easiest, with no particular problems Down-sun viewing presented the most serious problems in driving at low-sun angle, delineation of objects was extremely difficult, e g , rocks and bushes were hard to distinguish This condition was probably caused by the combination of similar-sized objects, glare, and shadows that appeared on the monitor under these conditions

CONCLUSIONS AND RECOMMENDATIONS

The tests described in this report offer firm proof that lunar and similar planetary surface navigation can be accomplished with the system used – a simple dead reckoning system, a monoptic TV camera, and 1 25 000 (or even 1.50 000) photographs and topographic maps

Occasionally, some confusion existed as to precise location, but doubts were resolved by the navigators themselves and generally in a short time. Furthermore, it is apparent from the log and other comments that the test subjects were operating under somewhat adverse conditions rough terrain made plotting and calculations difficult; the navigators were generally uncomfortable because of the rough ride, engine and generator noises were a small source of constant irritation, and, finally, the hours of constant navigation were long. In spite of this, excellent results were achieved. If the navigators had been situated in an air-conditioned room with plotting tables, computers, etc., at their disposal, the task of navigation would have been easier and more quickly accomplished, but the results would not have been more accurate

APPENDIX A

EFFECT OF GYRO UPDATING ON TRAVERSE CLOSURE ACCURACY

Gyros are subject to drift, thus losing initial inertial reference. Accuracy of a navigational system using a directional gyro will depend on how frequently the gyro is realigned to the initial direction.

To obtain an indication of this dependency, a four-sided course was laid out and traversed several times with varying numbers of updates. Total length of the course was 7.5 km An attempt was made to follow the identical course for each traverse (literally attempting to follow the preceding sortie tracks) to assure approximately the same environment, as well as using the same amount of time for each traverse. To make trends more pronounced, a very high drift rate of 9 deg/hr was chosen. The updating was done with the sun compass system described elsewhere The results are shown in Table A-1.

TABLE A-1. EFFECT OF GYRO UPDATING ON CLOSURE ERROR

Number of Updates	Time Used for Sortie (min)	Checkpoint Where Update Made	Closure Error (m)
0	86	NA	253
0	105	NA	330
1	120	CP-3	247
1	90	CP-2	272
3	81	CP-2, 3, 4	120
7	150	CP-2, 3, 4 and intermediate points	59

These results verify the obvious conclusion that closure error is reduced when updating is done more frequently. Figure A-1 is an analog plot (from the output of the navigation system) of a traverse with no update. The closure error is the distance between the terminated lines

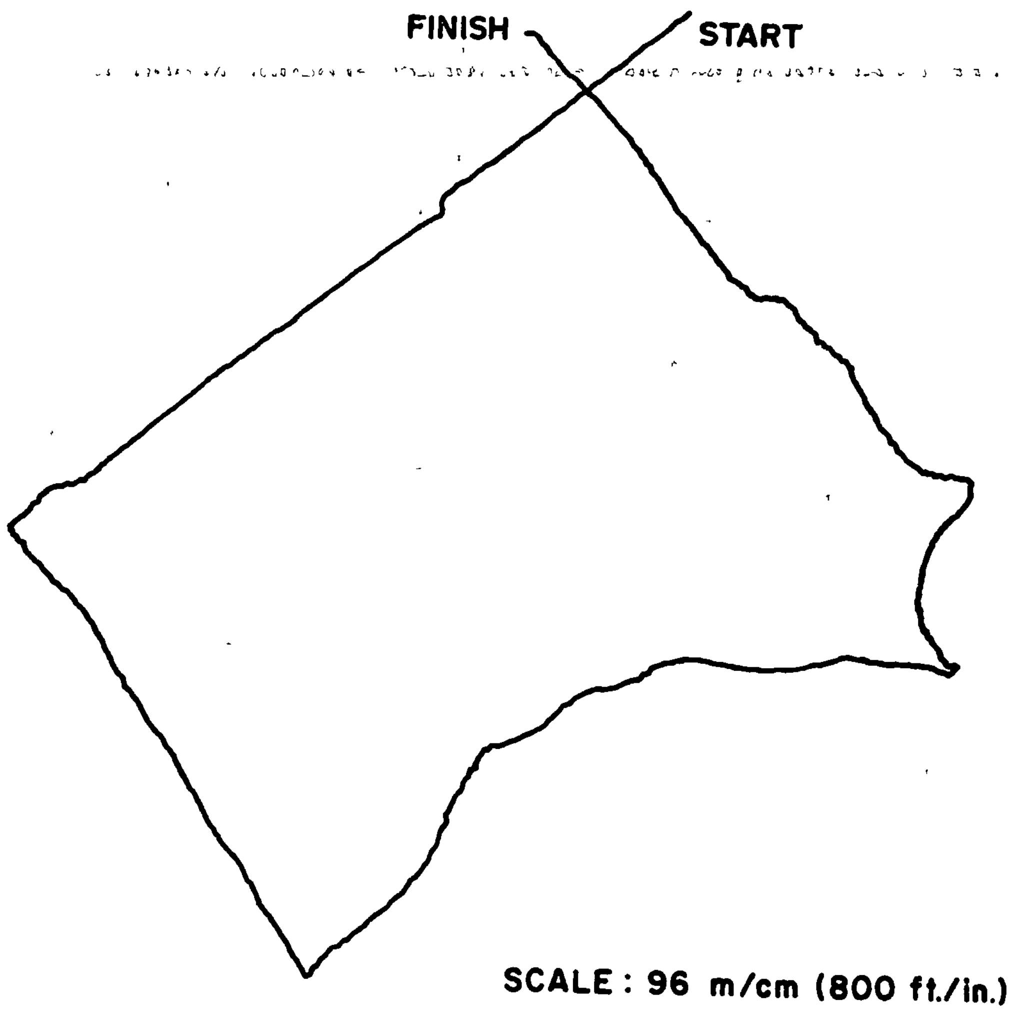

Figure A-1. Analog plot of a traverse.

APPENDIX B

GYRO UPDATE USING TV CAMERA AND PLANET

In these tests, the gyros were updated at intervals by determining azimuth with a sun compass device This device uses photocells to enable the operator to determine elevation of the sun The device could be automated and used on remote driving missions. However, the question arose as to the feasibility of using the TV camera to select a star or planet and in this way determine an azimuth using the stars' elevation and an ephemeris

The planet used was the evening star Venus An ephemeris was calculated for the date of the test, July 28, 1970 Before sunset, the sun compass was used to determine north accurately After sunset, Venus was located successfully with the TV camera Results were extremely good. The vehicle heading was determined to be 262 deg, 17 min, using the sun compass. Locating Venus on the TV monitor center mark gave the following readings

Time	Heading
8 30 p.m	262 deg, 14 min
8.34 p.m	262 deg, 34 min
8 42 p.m.	262 deg, 34 min
8 44 p.m	262 deg, 33 min
8·46 p.m	262 deg, 38 min

Thus, it appears to be entirely feasible to use the TV camera to determine heading from sufficiently bright heavenly bodies. However, vehicle attitude must be known to use the TV camera. Other tests performed show that first-magnitude stars can be detected even on a somewhat "snowy" picture

APPENDIX C

LOG OF SORTIE

Sortie "A"

LM to 1A (Flow Front)

Sortie A is shown in Figure 5 The sortie commenced at the site labeled "LM" at 10 35 a m July 23, 1970 Before leaving this site, position readouts were set to LM coordinates (N82 79 km, E7 51 km)[3] The camera on the Jeep was set at 350-deg pitch, which placed objects in the center of the monitor at a distance of 10.06 m (33 ft) in front of the Jeep. The sun is presently not shining, but viewing is good.

JULY 23, 1970

10 47 a m	N82 55 m, E7 63 m
10 50	Jeep has 10 deg nose down on road at N82 50 m, E7.65 m.
11 00	N82.36 m, E7 58 m, heading 240 deg
11 05	Covered camera on Jeep because of rain. Gassed up generators on both vehicles
11 18	Restarted sortie at N82.39 m, E7 57 m, flow front can be easily recognized
11 35	At flow front N82.26 m, E7 66 m, according to navigation system As a rough check on actually being at 1A, navigators aligned base of Merriam Crater with background peak on TV to give a line of sight intersecting at 1A
11 50	At N82.20 m, E7 66 m, tentatively identified CP2A, a large block. At this point, considerable time is spent in driving, i.e , hazard detection and obstacle avoidance No sun and still sprinkling rain.

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3 The first two digits of the coordinates are dropped to accommodate digital readout

12 00 noon	0.5-deg pitch up at N82.07 m, E7 67 m
12 20 p.m.	Reidentified CP2A at N81.79 m, E7 82m
12 40	12-deg pitch down, 0-deg roll
12 45	At CP2A. Navigation coordinates are N81.45 m, E8 13 m These were updated to target coordinates N81 41 m, E8 03 m.
1 07	Departed 2A for 3A with a pitch up of 8 deg at N81 33 m, E8.02 m.
1 14	Pitch is 0 deg at N81 20 m, E7 95 m Navigators feel that 0-deg pitch indicates they are on the lip of the crater
1:24	14 deg left side up (LSU) roll at N81 10 m, E7 68 m
1 35	Although navigators realized that they were west of target coordinates, they called N81 16 m, E7.52 m, CP3A although target coordinates of CP3A were N81 21 m, E7 605 m Description of 3A was "Interior of Spruhl Crater"
1.45	Lunch Break
2·35	Leaving CP3A. Stopped for visitors Resumed at 2 47.
2.52	Pitch angle of 8 deg at N81 29 m, E7 99 m
2 57	Back at CP2A Navigation system reads N81 40 m, E8 01 m Trouble at this point with telephones
3 15	Restart at heading of 35 deg Stopped for gyro update on the sun but is too overcast
3.35	Restarted
3 40	5-deg pitch at N81 74 m, E8 22 m
3·45	Navigation system coordinates are N81 98 m, E8 38 m
3 50	Target 4A (contact low flow front goes under steep flow front) can be recognized.

4.00	At CP4A Navigation system reads N82.78 m, E8 73 m Target coordinates are N82.65 m, E8 97 m Vehicle position was staked and position surveyed as N82.685 m, E8 955 m Both vehicles were position updated to N82 65 m, E8 97 m
4 05	Departed CP4A
4 25	Approaching 5A (base of Merriam Cinder Cone)
4 31	Arrived at CP5A Navigation system reads N81.88 m, E9.14 m, target is N81.9 m, E9 10 m. Vehicle position surveyed as N81 85 m, E9 04 m
4 37	Departed 5A on heading of 69 deg. Positions of vehicles staked.
4 40	Navigation system reads N81.88 m, E9 18 m, pitch is 13.5 deg
4 42	Jeep and Travelall stuck in loose soil at N82 09 m, E9 40 m
5 21	Restarted
5 23	The sun is visible and gyros on both vehicles were updated The Lear-Siegler gyro was set to 111 deg from 104 deg and the Bendix system gyro was set to 112 deg from 109 deg
6 00	N82 49 m, E9 83 m Heading for 6A is 77 deg
6 05	N82 51 m, E9 98 m Jeep has 15 deg right side up (RSU)
6.10	N82.45 m, E10.11 m, 11 deg RSU, 6 5 deg pitch up
6.22	Subjects feel they cannot negotiate slopes being encountered. Adopted a northerly heading of 11 deg and 10 deg RSU, 9 deg pitch down.
6.33	Following contour, N82 64 m, E10 57 m.
6 50	N82 50 m, E10 95 m, heading of 65 deg
6 55	N82.51 m, E11 03 m
6 59	Navigators decided to null out east coordinate and to take an east heading 9 deg RSU, pitch 3 deg up

7 20	Navigators are not confident that they understand 6A ("contact at edge of Merriam Cinder fan") Since agreement of coordinates appeared to be good, the prominent ridge was selected as the contact N83 42 m, E11 82 m, (Jeep), N82 90 m, E11 77 m, (Travelall), target coordinates are N82 89 m, E11 59 m. Vehicles secured and left overnight CP6A

JULY 24, 1970

9 15 a.m.	Arrived at CP6A Readied vehicles and laid out candidate positions from which landmark updates might be done Updated gyros and Jeep coordinates to those of the Travelall. N82.90 m, E11.79 m
11 00	Departing CP6A on heading of 73 5 deg
11 10	Swinging angles on two peaks, left peak 350 5 deg, right peak 11 0 deg, heading 165 0 deg, N82 75 m, E12 03 m
11 20	Navigators agree that if present position is correct, heading for the left mountain should lead to CP7A We think we can see target, a low ridge CP7A flow front (young Merriam flow) and Cinder Slope (Merriam Fan)
11 32	RSU 12 deg We should be rounding east edge of slope (of Merriam)
11 35	Decided to adopt a more easterly heading to eliminate some of the roll attitude, N81 93 m, E12.16 m
11 50	Identified CP7A N81 75 m, E12.17 m (Travelall), N81.82 m, E12.43 m (Jeep), updated positions of both vehicles to N82.04 m, 12 03 m
11 55	Departed CP7A Plan is to go down road to N81 30 m and turn left It has been overcast since 11 30 but visibility is acceptable
12 00 noon	Swing angles on two peaks, notch of peak 1 is 342 0 deg and peak 2 is 5 0 deg. Heading is 174 5 deg N81.50 m, E11 92 m
12 10 p.m	At N81 34 m, E11 92 m, left road on heading of 115 deg
12 17	At N81 08 m, E12.14 m, changed heading to 107 deg. Think we can see flow front.

12 23	Heading of 95 deg at N81 05 m, E12 21 m.
12 30	Identified flow front Jeep staked at N80 99 m, E12.59 m Drove Travelall until a prominent flow was reached at N80.96 m, E12 41 m At this point, Travelall updated to N80 99 m, E12 58 m Jeep not updated at CP8A.
12 45	Lunch Break.
1 15	Departed CP8A Checkpoints 9A and 10A bypassed because of the obviously rough terrain Next target is 11A.
1 23	Spotted fence and what appears to be a gate Zoom on camera very helpful
1 30	Approaching gate (CP11A) From this "certain" update, we can tell how far we missed CP8A
1 40	Positions updated at CP11A Jeep updated from N80.60 m, E12 32 m, to N80 44 m, E11 89 m Travelall updated from N80 68 m, E12 13 m, to N80 44 m, E11 89 m.
1 50	Stopped at N80 17 m, E12 03 m to swing angles on the same two peaks, peak 1 is 27.15 deg, peak 2, 342.5 deg, and heading, 155 deg
2 00	Arrived at N79 80 m on road. Will take heading of 146 deg to go to CP12A
2 10	Noticed discrepancy in gyro headings. Jeep has 121 deg, Travelall is 136 deg Coordinates are N79 75 m, E12 29 m (Jeep), N79 71 m, E12 02 m (Travelall) Vehicles were aligned and camera swung from intersection of slope of peak 1 and horizon to peak 2 to obtain 74 deg This agrees with protractor measurements
2 15	Based on this information, the Travelall gyro was updated from 136 5 deg to 141 deg and the Jeep gyro from 123 deg to 141 deg This was based on confidence in our position and recognition of landmarks
2 24	Think we can identify target (12A – S Sheba Mar Reservation fence), a ridge upon a ridge, N79 56 m, E12 14 m

2 40	Have come to hard-surfaced road. We identify our position as being about what it should be. Have stopped because of rain
3 10	Restarted.
3:15	N79.18 m, E12.52 m (Travelall), N79 21 m, E12 84 m (Jeep).
3:25	N78.72 m, E12 77 m
3 32	Noticed an apparent difference in gyro headings of the two vehicles. Plot of Travelall's coordinates places us on the proper path
3·35	On pipeline at N78.31 m, E13.04 m (Travelall), N78 41 m, E13 49 m (Jeep)
3·50	N77 94 m, E13 41 m.
4·05	Looking at the draw we want to enter that lies east of us, N77.75 m, E13.65 m.
4.15	Identified lava flow and fence, N77.65 m, E13 76 m
4 20	At CP12A we can see lava flow and fence The Jeep's coordinates, N73 87 m, E14 40 m, were updated to those of the Travelall's, N77 64 m, E13.81 m.
4 25	Jeep heading is 84 deg, Travelall's 91 deg Jeep updated to 91 deg.
4 50	Can identify rise in middle of opening
4:55	N76.89 m, E13.56 m
5:00	N76.72 m, E13.48 m
5 10	Have hit road and can see pipeline running alongside Coordinates indicate we are somewhat east of intersection of road and pipeline Before intercept, heading was more easterly than required Reason for this was to get Jeep off of slope, therefore, a path was taken along the saddle
5 12	Difficult to see because of sun glare

5 18	Coordinates indicate we are at 13A, N76.49 m, E12 94 m
5 33	Navigators were not accurate in plotting nor reading the coordinates Present coordinates indicate we are too far west for intersection We are turning around to find road intersection
5 45	Still going easterly on road We can see the intersection ahead N76 44 m, E13 45 m (Travelall), N76.41 m, E13 53 m (Jeep), updated both systems to N76 38 m, E13 10 m
6 00	Updated gyros by sun update at 13A Updated Travelall from 77 5 deg to 92 0 deg Updated Jeep from 120 deg to 130 deg
6 15	Restarted sortie Will traverse road until we reach N75 60 m
6 25	N75 65 m, E13 12 m (Travelall), N75 59 m, E12.86 m (Jeep) For some reason, Jeep coordinates appear to be in error
6·27	Taking heading of 145 deg Using Travelall's coordinates of N75 60 m, E13 12 m. Leaving road
6 47	Identified flow front At first it appeared to be Sheba Mountain Shows how heights and distances can interchange N75 30 m, E13 38 m (Travelall), N75.27 m, E13 17 m (Jeep) We think we may have gone too far south. TV picture indicates we should possibly go north and west to get to CP14A
7 00	Secured vehicles for the night at CP14A

JULY 25, 1970

9 00 a m	Arrived at 14A Vehicles being checked out and gyros aligned to sun Coordinates of both vehicles updated to those of 14A N75 30 m, E13 06 m
10 15	Departed from 14A to 15A on heading of 167 deg
10 27	N74 46 m, E13 29 m (Travelall), N74 42 m, E13 30 m (Jeep)
10.30	Tachometer reads 1400 rpm (approximately 17 8 m/s)
10 35	N74 04 m, E13 38 m (Travelall), N73 98 m, E13 40 m (Jeep)

10 43	N73.71 m, E13.45 m (Travelall), N73.64 m, E13 47 m (Jeep) Recognized landmarks – three piles of rocks that were visible on 1 25 000 photo, left on heading of 170 deg.
10 55	N73.39 m, E13.53 m (Travelall), N73 32 m, E13 55 m (Jeep).
11 02	Recognized road at 20.17 m (66 ft) N73.11 m, E13.60 m (Travelall), N73 06 m, E13 62 m (Jeep). Encountering rocks
11 07	Recognized wash area N72 96 m, E13 64 m (Travelall), N72.89 m, E13 66 m (Jeep)
11 17	N72 85 m, E13 65 m (Travelall), N72 77 m, E13 67 m (Jeep) Recognized position on 1 25 000 photo. Updated both vehicle coordinates to N72 75 m, E13 62 m
11 28	Agreed to have someone guide us across because of steepness of wash walls
11·43	Stopped for lunch in ravine Surrounding area not visible. Gyro headings are 255 5 deg (Jeep), 228.6 deg (Travelall)
12 43 p m.	Gyro headings are 252 5 deg (Jeep), 231 deg (Travelall) Updated by sun to 258 deg (Jeep), 232 deg (Travelall)
12 50	Departed 15A for 16A
1.13	N72.70 m, E12 71 m (Travelall), N72.72 m, E12.54 m (Jeep) Heading of 257 deg Using some time in checking on ability to determine size of rocks
1 27	N72.61 m, E12 25 m (Travelall), N72 61 m, E12 07 m (Jeep) Heading of 224 deg
1:40	N72.55 m, E12 05 m (Travelall), N72.53 m, E11 80 m (Jeep) Jeep heading of 260 deg Graphed heading of 250 deg to reach 16A
1 50	Sighted 16A (ranch house)
2 00	Ran out of gas in Jeep generator – regassed
2:18	Reached 16A N72 07 m, E11.55 m (Travelall), N71.95 m, E11 12 m (Jeep) Updated both to N72 21 m, E11 05 m

2 30	Jeep driver noted pitch-down of 6 deg but did not detect on screen Backed up to check on why it was not detected Determined that camera should be tilted down more to detect ditches, etc.
2 41	Trying position and heading update from landmarks
3 00	Jeep heading of 180 deg N71 51 m, E10 41 m (Travelall), N71 38 m, E10 53 m (Jeep) Left to Merrill 28 deg, graphically should be 12 deg Right to A 150 deg, graphically should be 136 deg
3 05	Restarted Heading of 205 deg
3 20	Stopped to check maps. Driving is easier with camera tilted down, but driver loses sight of steering landmarks and must rely on dial for heading
3 50	Reached 17A N70 72 m, E10 12 m (Travelall), N70 52 m, E10.49 m (Jeep)
4 18	Gyro update from sun compass Jeep heading of 175 deg updated to 195 deg Travelall heading of 190 5 deg updated to 188 deg Note Landmark fix at 3 00 showed Jeep had heading error of 16 deg See sun update of 20 deg at 4 18
4 23	Left 17A for 18A 11-deg pitch up, 3-deg LSU
4 53	N70 13 m, E10 64 m (Travelall), N70 03 m, E10 55 m (Jeep). Jeep heading 134 deg, Travelall heading 130 deg Taking new heading of 160 deg
5 03	N69.84 m, E10 96 m (Travelall), N69 72 m, E10 82 (Jeep).
5 09	3-deg pitch up, 1-deg RSU
5 12	8-deg pitch up, 7-deg RSU.
5 13	10-deg pitch up, 3-deg RSU.
5 15	17-deg pitch up, 3-deg RSU

5 16	16-deg pitch up, 10-deg RSU.
5 17	16-deg pitch up, 10-deg RSU
5:18	10-deg pitch up, 10-deg RSU
5.50	Reached 18A. N69.34 m, E11 08 m (Travelall), N69 18 m, E10.82 m (Jeep) Target coordinates were N69.16 m, E10 75 m
6 15	Departed 18A with updated coordinates of 18A to return to LM site with Travelall
7.30	Arrived at LM site. N81 72 m, E5 98 m (Travelall) LM coordinates N82.79 m, E7 51 m

Sortie "B"

JULY 29, 1970

9 10 a m	Commenced sortie from LM site
9 24	9-deg pitch up.
9.26	7- to 8-deg pitch up, 5- to 8-deg LSU
9.37	N83.52 m, E7 58 m (Travelall), N83.53 m, E7 46 m (Jeep)
9 46	Reached level area. Point 1. N83.55 m, E7.59 m (Travelall), N83.55 m, E7 45 m (Jeep). Updated Jeep gyro from 18 to 22 deg. Updated coordinates to N83 48 m, E7 50 m Recorded 10-deg roll into draw
10 27	N83.73 m, E7 94 m (Travelall), N83 71 m, E7 95 m (Jeep) Graphed 75-deg heading to next point Recorded 3-deg pitch down, 3-deg LSU. Landmark sightings Jeep heading 85 deg N83.83 m, E8 35 m (Travelall), N83 80 m, E8 37 m (Jeep) Angle to Merriam 77.5 deg, angle to rock 312 deg
11·03	Heading 50 deg – found path through flow front
11 18	N83.86 m, E8 61 m (Travelall), N83 82 m, E8 64 m (Jeep)
11 31	N83.85 m, E8.79 m (Travelall), N83 88 m, E8 80 m (Jeep) at 2B

11 46	Stopped for lunch N83 79 m, E8 40 m (Travelall), N83.76 m, E8.43 m (Jeep). From landmark graph, correct Jeep heading 5 deg
12 35 p.m	By identifying position on map, updated both systems to N83.89 m, E8 43 m. During lunch, Travelall gyro drifted 1.5 deg, Jeep drifted -16 deg
12 40	Departed with heading of 20 to 25 deg.
1 35	N84 90 m, E9 32 m (Travelall), N85 32 m, E8 97 m (Jeep)
2 02	Sun compass update on Travelall from 49 deg, 30 min to 42 deg, 15 min, on Jeep from 41 deg to 41 deg, 30 min Updated coordinate to N85.70 m, E85 70 m
2 51	At CP3A Head of canyon between Crater 178 flow and KR flow scarf N85 85 m, E9.50 m (Travelall), N85 83 m, E 9 49 m (Jeep)
3 00	Departed 3A.
4 20	N86.45 m, E9 99 m (Travelall), N86 65 m, E10 24 m (Jeep) Heading is 9 deg to reach target N87 25 m, E10 35 m Updated coordinates at road intersection from N86 92 m, E9.85 m (Travelall), N87 24 m, E10 30 m (Jeep) to N87 35 m, E10.40 m On heading of 28 deg Landmark update Jeep from 64 deg to 28 deg, Travelall from 36 deg to 28 deg
5 26	Sun update Travelall from 21 deg, 30 min to 26 deg, 13 min, Jeep from 22 5 deg to 32 48 deg
6 10	CP4B N87.98 m, E10 88 m (Travelall), N88 01 m, E10 99 m (Jeep). Crossed wide area of fine, soft lava between 3B and 4B, causing a considerable error in coordinates Five hours without sun update giving heading error Secured vehicles for the night.

JULY 30, 1970

11 00 a m	Sun update Updated coordinates in both vehicles to N88 81 m, E11 20 m
11 30	Departed for 5B

11 45	N89.24 m, E11.63 m, heading of 49 deg
11 47	Camera iris adjustment. Sun near zenith Bushes and rocks are distinguishable
12 25	Landmark scan to detect site. New heading of 31 deg
12 45	Cloud shadow making camera viewing difficult
12 50	Called site 5B N89 85 m, E12 28 m (Travelall); N89 95 m, E12 20 m (Jeep) Updated coordinates to N89 80 m, E12 57 m. Stopped for lunch
1 35	Reset gyros for drift occurring during lunch. Jeep from 76 deg back to 82 deg, Travelall from 67 5 deg back to 69 deg
1 40	Departed 5B for 6B There is a known error on 5B Should have looked for Kaibob (yellowish limestone outcropping). Not knowing description of Kaibob, we looked for black outcropping and called that point 5B
2 30	Sun update. Jeep to 58 deg, 23 min from 16 deg
2 35	Proceeding toward 6A (Spur of Roden flow) Pitch meter is broken
3 10	At 6B N90 58 m, E14 08 m (Travelall), N90 93 m, E13 91 m (Jeep) Updated to 6B coordinates N89 88 m, E13 00 m
3 30	Spark plug on Honda generator fouled Cleaned and restarted
3 40	Departed 6B for 7B 132-deg heading
4 00	Having found definite checkpoint (6B, Roden Spur), we judged that the point we called 5B was where 4B should be, and the point we called 4B was about 2 km short The errors estimated for slippage in lava flow were overestimated, and the wrong gully was selected as 4B This helped to lead to a wrong selection of 5B, along with not knowing that a Kaibob outcropping is white
4 15	Travelall overheated. Poured water over radiator to cool. Accidentally got visual view of 7B while working on generator

4 22	At 7B N89.58 m, E13.44 m (Travelall), N89 69 m, E13.49 m (Jeep) Updated both to N89 57 m, E13.40 m
4 27	Departed 7B for 5B
4 35	Updated Jeep gyro to Travelall gyro from 258 deg to 284 deg
5 15	At 5B N89 68 m, E12 48 m (Travelall), N89 59 m, E12.47 m (Jeep) Updated both to 5B coordinates N89.80 m, E12.57 m Shut down gyros and secured for the night

JULY 31, 1970

9 50 a m	Started gyros Sun updated Travelall to 220 deg, 30 min from 214 deg, 30 min, Jeep to 247 deg, 3 min from 225 deg
10 10	Departing 5B for 8B Vehicle went through loose lava; wheels spinning some
10 28	N89 88 m, E11 40 m, heading 265 deg (Travelall), N89 91 m, E11 48 m heading 263 deg (Jeep)
10 45	Heading of 265 deg
11 00	N89 93 m, E10.35 m, heading 282 deg (Travelall), N89.88 m, E10 42 m, heading 267 deg (Jeep) Recognized area on monitor that agrees with photo Brush caught under Jeep and caught fire Extinguished with Jeep-mounted extinguisher
12 53 p m	Arrived at 8B N89 94 m, E9 40 m (Travelall); N89.78 m, E9 46 m (Jeep) Map N89 89 m, E9 36 m Chose point from map rather than gate described on comment sheet End of sortie

APPENDIX D

DRIVING TESTS IN CRATER FIELD

PURPOSE

Six runs were made in the crater field simulating a lunar landing site. The goals of these tests were:

1. To evaluate the remote-viewing driving capability in surface topography similar to that on the lunar surface.

2. To compare the effect of varying camera height on driving ability.

3. To determine the ability to estimate distances and obstacle sizes for the purpose of "camera off" driving.

4. To navigate in a crater field by driving from one point to another and investigating particular craters, predetermined from photographs, along the path.

GENERAL DESCRIPTION

The camera heights used were 1.98 m (6.5 ft), 1.75 m (5.75 ft), and 2.59 m (8.5 ft). Two paths were laid out in the crater field, and a test run was made on each path at each of the camera heights. Four drivers were used in a sequence so that one did not repeat a test run on a path. This was done to prevent familiarity with the path, which would influence driving ease. The TV picture was transmitted from the Jeep to a ground station, where another man assisted the driver in path determination and crater recognition.

A photograph of the crater field with the traverse end points and target craters is given in Figure D-1. The distances between end points of the two paths were 251.1 m (824 ft) and 205.7 m (675 ft). The crater diameters varied from 0.60 m (2 ft) to 18.29 m (60 ft), with an average of about 9.15 m (30 ft).

The traverses were not run in the shortest possible time, although this would have been a good criterion for determining the more suitable camera height. The speed was held down to evaluate distance estimates, to describe ability to see points of possible geological interest, etc.

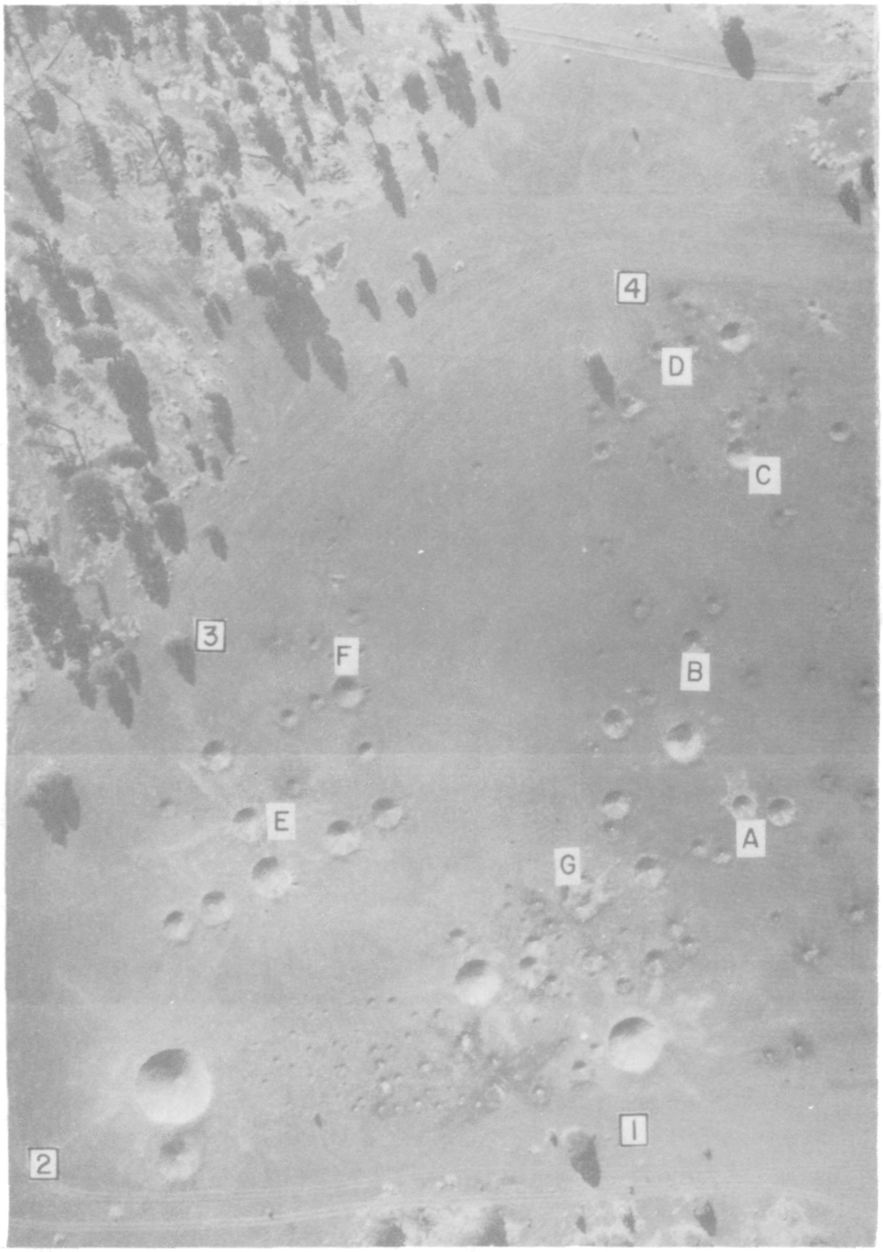

Figure D-1. Crater field.

Target distance as a function of camera elevation angle, determined empirically for the three camera mounting positions, is given in Table D-1.

TABLE D-1. DISTANCE VERSUS CAMERA ELEVATION ANGLE

Camera Elevation Angle (deg)	Distance m (ft)		
		Camera Heights, m (ft)	
	1.75 (5.75)	1 98 (6 5)	2 59 (8 5)
330	2 74 (9)	2 74 (9)	2.44 (8)
340	4.57 (15)	4 57 (15)	5 33 (17 5)
345	6 40 (21)		8 23 (27)
350	9 75 (32)	10.06 (33)	14 63 (48)
352			20 57 (67 5)
353 5			30.48 (100)
355	21.95 (72)	20 12 (66)	
360	27 43 (90)		

DISCUSSION

Operators were able to drive in the crater field without undue difficulty Progress was considerably slower than driving in the desert because of the greater density of obstacles Individual driver skill naturally affected the ease with which the field areas were traversed The ability to drive by TV monoptic viewing was demonstrated beyond doubt

The highest camera mounting position proved to be the best for driving and navigating Having the front of the vehicle in the view with the path to be traversed provided orientation and increased speed, as the driver did not have to stop and tilt the camera down to circumnavigate obstacles The higher mounting also enabled the camera operator to see into craters for visual investigation A better and more distant view of the path to be traversed could be obtained.

The lowest mounting position cut down on the distance seen ahead and gave no help in driver orientation This position was very poor for close driving because of the small ground area in the field of view, but it improved the ability to judge crater rim heights

Most of the distance estimations were very good The accuracy of distance determination from the camera pitch angle depended upon the levelness of the terrain Estimates of distance to crater rims were long because the rims were raised

Of the 18 distance estimations made, the average error was 1 097 m (3 6 ft). This indicates that camera-off driving for estimated distances along clear paths would be safe

Estimates of obstacle sizes depended to a great extent upon having something in view with which to compare them In this light, having some part of the vehicle in view was helpful Estimating distances to the obstacles also helped in estimating their size

Particular craters along the traverses were found easily A comparison of crater patterns on the TV monitor with those on the photograph was no problem, especially with the highest camera mount Note that the photograph used here was of a much higher resolution than those from the Orbiter

Traverse times are given in Table D-2 As stated before, no conclusions concerning nominal driving speeds can be drawn from these times, as no real effort was made to keep traverse times down Unavoidably, the drivers were becoming more familiar with the traverses as time progressed No set number of distance estimates was made on each traverse, so this was a factor in traverse time

The test log is included here

TABLE D-2 TRAVERSE TIMES

Camera Height m (ft)	Traverse Time	
	1–4	3–1
1.98 (6 5)	1 hr, 20 min	1 hr, 18 min
1 75 (5 75)	48 min	1 hr, 4 min
2 59 (8 5)	52 min	35 min

CRATER FIELD LOG

AUGUST 4, 1970 – CAMERA HEIGHT – 1.98 m (6.5 ft)

2·30 p.m.	Started at point 1 Note camera washout at higher elevation angles
2:40	Traverse stopped by rain.
3 00	Rain ceased Resumed traverse
3.09	Panned for position fix
3 15	Estimated distance to junction of two craters 0 91 - 10 67 m (3 - 35 ft), measured 13.10 m (43 ft)
3 22	Reached crater pan A
3 30	Have bypassed B, recognized fact upon sighting unusual pair of craters and recognizing position from comparison with photo Decided to proceed to point C
3 45	Driving with monitor off and advancing estimates of distances
3 50	Identified crater C. Distinguished string on ground 1 83 m (6 ft) in front of vehicle
3.53	Ran 0 60 m (2 ft) from rim of small crater in obstacle avoidance test
4.00	Identified crater D Estimated distance 13 72 m (45 ft), measured 13 10 m (43 ft)
4·10	Completed traverse at point 4
4 22	Started traverse 2 at point 3
4 25	Recognized crater F from distance of 39 62 m (130 ft), crater rim 0 60 m (2 ft) high.
4 30	Estimated distance to edge of crater F at 9.14 m (30 ft), measured 9.75 m (32 ft)

4:35	Driving between two craters; 1 83 m (6 ft) from one on right, on rim of one on left
4 40	Recognized crater E from 21 34 m (70 ft) Estimated a rock size at 0 45 m (18 in) wide, 0.60 m (24 in.) high, measured 0.45 m (18 in.) wide, 0.60 m (24 in.) high.
	Note Top of rock blended with side to cause error in height estimate
4·45	Estimated distance of 2.74 m (9 ft) from edge of crater F; measured 2 44 m (8 ft)
4.48	Steering through rocks well executed
5 07	Identified crater G. Estimated 4 57 to 6.10 m (15 to 20 ft) from edge; measured 6.70 m (22 ft)
5.10	Driver and aide recognized boulders, searched for best path to point 1.
5:15	Drove through small crater which was 1.83 m (6 ft) wide and 0.45 m (18 in) deep, saw boulder directly ahead, correctly estimated size as 0 91 m (3 ft) long, 0 45 m (18 in.) high.
5.30	Reached point 1

AUGUST 5, 1970 – CAMERA HEIGHT – 1 75 m (5 75 ft)

8 48 a.m.	Start at point 1
8:51	Checked progress past first big crater
	Note Good definition of crater with rims 3 m high or greater with camera at this height. Craters with little or no rims were not well defined.
8 58	Stopped for distance estimate to crater pair A. Estimated 9 75 m (32 ft), measured 11.28 m (37 ft)
9 04	Identified crater B from 34 75 m (114 ft) Used small crater position as check
9·11	Estimated distance to crater B at 6.40 m (21 ft), measured 5 94 m (19 5 ft)

9 19	Identıfied crater C from 40.23 m (132 ft)
	Note Small craters beyond C appeared as dark blur rather than as dıstınct craters wıth thıs camera height
9.24	Estımated dıstance to crater C as 9 75 m (32 ft), measured 9 14 m (30 ft). Drıver ıdentıfıed a small nll runnıng from crater C as a small dıtch
9 27	Properly ıdentıfıed crater D whıle stopped besıde crater C.
9 28	Estimated dıstance to poınt between craters at D as 6 40 m (21 ft), measured 5 49 m (18 ft)
9.30	Drove between craters at poınt D and to right of small crater. Wıth thıs camera heıght, the fıeld of vıew was too small when tılted down for close drıvıng
9 36	Reached poınt 4 End of traverse

TRAVERSE FROM POINT 3 TO POINT 1

9 51 a.m.	Start
10 02	Measured 57 deg to left of crater in front of E.
10 06	Dıstance estımated 9.14 m (30 ft); measured 12.80 m (42 ft)
10 13	Stopped by hazard avoıdance Lost orıentatıon when turnıng and backıng
10 25	Properly identıfıed crater F from west sıde of small crater Estımated dıstance as 18 29 m (60 ft), measured 21.03 m (69 ft)
10 30	Drove to estımated dıstance of 4.57 m (15 ft) from crater F, measured 3 35 m (11 ft)
	Note. Rocks of stratıfied regıon of crater wall accurately descrıbed from TV pıcture
10.38	Determıned need for 180 deg turn to proceed to crater G
10 44	Recognızed rıng of lıght-shaded rocks surroundıng crater G.

10 52	Drove through small crater – 1.22 m (4 ft) diameter, 0.30 m (1 ft) deep – without commenting Properly identified reading crater G Estimated distance at 4 57 m (15 ft), measured 5 5 m (18 ft).
10 55	Rain started. Ended traverse.

CAMERA HEIGHT 2.59 m (8.5 ft)

2.10 p m.	Started traverse at point 1, target point 4. Noted much better definition of objects at a distance with this camera height – easier to orient vehicle to surroundings
2 20	Identified crater A – estimated distance as 30.48 m (100 ft), measured 31.09 m (102 ft), had tentative identification from 60 96 m (200 ft) Drove to estimated distance from crater A of 2 44 m (8 ft), measured 1 98 m (6 5 ft)
2 30	At crater B, identified from a distance of 42 98 m (141 ft).
2 37	Tentative identification of crater C at 45.72 m (150 ft).
	Note Definition of small shallow craters not as good at short range with this camera height as with the two lower heights
2 45	Identified crater D from an estimated distance of 33 53 m (110 ft), measured 31 39 m (103 ft) Drove to crater Could distinguish small objects [to 2 54 cm (1 in) diameter] in bottom of crater.
3 00	Drove between two craters 2 74 m (9 ft) apart very easily
	Note Being able to see front of vehicle in camera greatly increased confidence in driving
3:02	Ended traverse at point 4

TRAVERSE FROM POINT 3 TO POINT 1

3:15 p m	Start
3:17	Correctly identified point E from near starting point.
3:21	Drove to E Estimated distance as 5.33 m (17.5 ft), measured 4 88 m (16 ft) Could see path through rocks clearly

3 27	Correctly identified crater F while parked by crater E.
3:31	Estimated distance to rock as 5 33 m (17.5 ft) and rock dimensions as 0.30 m (12 in.) wide and 0.20 m (8 in) high; measured 5 33 m (17 5 ft), 0.35 m (14 in) wide, and 0 23 m (9 in) high.
3 36	To check driving ability, drove left front wheel onto rim of crater; used camera to investigate crater interior
3:38	Made proper turn to right to search for crater G.
3 40	Easily avoided small crater in front of crater G.
3 42	Drove to estimated distance of 0 30 m (1 ft) from G, measured 0.45 m (1 5 ft).
3 45	After leaving G, observed small crater 0 91 m (3 ft) in diameter, 0.15 m (6 in) deep.
3:50	Ended traverse at point 1.

APPROVAL

FIELD TESTS USING DEAD RECKONING AND MONOPTIC VIDEO FOR REMOTE LUNAR SURFACE NAVIGATION

By William C. Mastin and Peter H Broussard, Jr .

The information in this report has been reviewed for security classification Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer This report, in its entirety, has been determined to be unclassified

This document has also been reviewed and approved for technical accuracy.

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